

PHY 114 A General Physics II
11 AM-12:15 PM TR Olin 101

Plan for Lecture 4:

1. Introduction to the electric potential
2. Relationship between the electric potential and the electric field

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Announcements:

No.	Lecture Date	Topic	Text Sections	Problem Assignments	Assignment Due Date
1	01/19/2012	Coulomb's law	23.1-23.4	23.6 , 23.8a , 23.13	01/24/2012
2	01/24/2012	Electric field	23.4-23.7	23.22 , 23.20 , 23.61a	01/26/2012
3	01/26/2012	Gauss's Law	24.1-24.3	24.22a , 24.23 , 24.40	01/31/2012
→ 4	01/31/2012	Electric potential	25.1-25.4	25.12 , 25.23 , 25.34 , 25.01	02/02/2012
5	02/02/2012	Electric potential	25.5-25.8	(Review for exam)	
	02/07/2012	Exam			

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i-clicker question

Would you attend a review session for next Tuesday's exam on

A. Monday afternoon at 4 PM
 B. Monday evening at 5 PM
 C. Sunday afternoon at 3 PM
 D. Sunday evening at 5 PM
 E. None of these

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i-clicker registration problems:

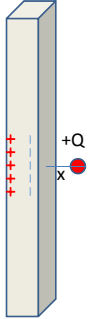
- Campbell, Thane
- Dearmon, Jake
- Klebous, Sandy
- Samsel, David
- Story, William

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Consider a neutral (electrically isolated) metal sheet:



What happens when you bring a point charge +Q close to the sheet?

Image charge effect due to metal sheet

$$\mathbf{F} = -\frac{k_e Q^2}{(2x)^2} \hat{\mathbf{x}}$$

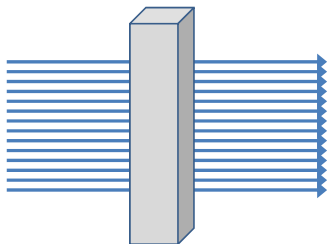
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Somewhat related question from homework:

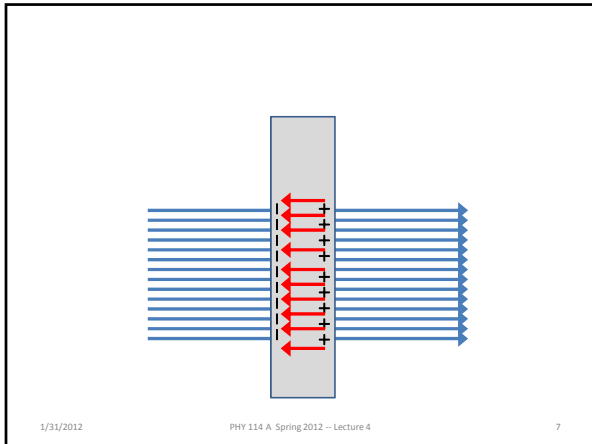
Suppose an electrically neutral sheet of metal is placed in a uniform electric field. What is the resultant charge distribution on the surface of the sheet?



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Electric field inside an electric isolated, neutral ideal metal = 0.

Gauss's Law for cylinder:

$$0 + EA = \frac{Q_{in}}{\epsilon_0}$$

$$\frac{Q_{in}}{A} = \sigma = \epsilon_0 E$$

A diagram showing a vertical grey rectangular plate with positive charges (+). A purple cylindrical Gaussian surface is drawn, partially inside the plate and partially in the air. Blue arrows represent the electric field E pointing to the right. The area of the cylinder's end face is labeled EA . The region inside the metal is labeled 0 .

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Review of work and potential energy

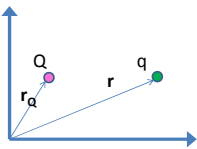
A diagram showing a 2D coordinate system with x and y axes. A force vector \mathbf{F} points downwards. A path is shown from an initial position \mathbf{r}_i to a final position \mathbf{r}_f . A small displacement vector $d\mathbf{s}$ is shown along the path.

Work : $W = \int_{\mathbf{r}_i}^{\mathbf{r}_f} \mathbf{F} \cdot d\mathbf{s}$

For conservative \mathbf{F} : $W = \int_{\mathbf{r}_i}^{\mathbf{r}_f} \mathbf{F} \cdot d\mathbf{s} = -(U_f - U_i)$

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Application of work principles to Coulomb's law force



$$\mathbf{F}(\mathbf{r}) = \frac{k_e q Q}{|\mathbf{r} - \mathbf{r}_Q|^2} \frac{\mathbf{r} - \mathbf{r}_Q}{|\mathbf{r} - \mathbf{r}_Q|}$$

$$W = \int_{\mathbf{r}_Q \rightarrow \infty}^{\mathbf{r}} \mathbf{F}(\mathbf{r}') \cdot d\mathbf{r}' = -\frac{k_e q Q}{|\mathbf{r} - \mathbf{r}_Q|} = -(U(\mathbf{r}) - U_\infty)$$

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Potential energy due to Coulomb's law with charges q and Q :

$$U(\mathbf{r}) = \frac{k_e q Q}{|\mathbf{r} - \mathbf{r}_Q|} \quad (\text{joules})$$

Electric potential due to charge Q :

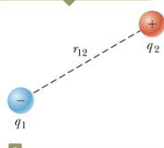
$$V(\mathbf{r}) = \frac{k_e Q}{|\mathbf{r} - \mathbf{r}_Q|} \quad (\text{joules/C} \equiv \text{Volt})$$

Electric potential due to many charges Q_i :

$$V(\mathbf{r}) = \sum_i \frac{k_e Q_i}{|\mathbf{r} - \mathbf{r}_{Q_i}|}$$

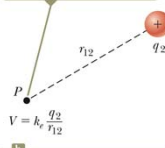
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The potential energy of the pair of charges is given by $k_e q_1 q_2 / r_{12}$.



a

A potential $k_e q_2 / r_{12}$ exists at point P due to charge q_2 .



b

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Examples of spatial distribution of electric potential

$$V(x, y) = \frac{k_e Q}{\sqrt{x^2 + y^2}}$$

$$V(x, y) = \frac{k_e Q}{\sqrt{(x+a)^2 + (y+a)^2}} + \frac{-k_e Q}{\sqrt{(x-a)^2 + (y-a)^2}}$$

The red-brown curve shows the $1/r$ nature of the electric potential as given by Equation 25.11.

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i-clicker exercise:

Choose the expression which corresponds to the value of the electrostatic potential at the center of the square in the diagram.

A. 0
 B. $\frac{4k_e Q}{d}$
 C. $\frac{8k_e Q}{d}$
 D. $\frac{\sqrt{32}k_e Q}{d}$
 E. None of these.

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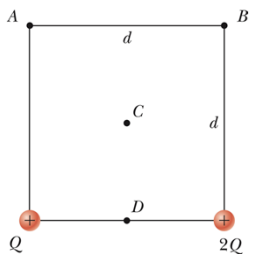
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Calculation of the electrostatic potential at points A,B,C,D:



$$V_A = \frac{k_e Q}{d} + \frac{2k_e Q}{\sqrt{2}d}$$

$$V_B = \frac{2k_e Q}{d} + \frac{k_e Q}{\sqrt{2}d}$$

$$V_C = \frac{k_e Q}{d/\sqrt{2}} + \frac{2k_e Q}{d/\sqrt{2}} = \frac{3\sqrt{2}k_e Q}{d}$$

$$V_D = \frac{k_e Q}{d/2} + \frac{2k_e Q}{d/2} = \frac{6k_e Q}{d}$$

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Relationships between electric potential and electric field:
 E has units N/C
 V has units J/C=Volt

$$V(\mathbf{r}) = -\int_{\infty}^{\mathbf{r}} \mathbf{E}(\mathbf{r}') \cdot d\mathbf{r}'$$

$$\mathbf{E}(\mathbf{r}) = -\nabla V(\mathbf{r}) = -\hat{i} \frac{\partial V(\mathbf{r})}{\partial x} - \hat{j} \frac{\partial V(\mathbf{r})}{\partial y} - \hat{k} \frac{\partial V(\mathbf{r})}{\partial z}$$

Aside -- connection to Gauss's Law

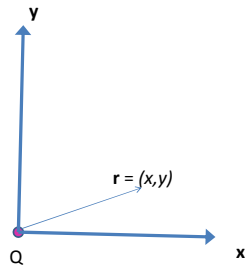
$$\nabla \cdot \mathbf{E} = \frac{\rho(\mathbf{r})}{\epsilon_0}$$

$$\mathbf{E}(\mathbf{r}) = -\nabla V(\mathbf{r}) \Rightarrow \nabla^2 V(\mathbf{r}) = -\frac{\rho(\mathbf{r})}{\epsilon_0}$$

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$$V(\mathbf{r}) = \frac{k_e Q}{\sqrt{x^2 + y^2}}$$

$$\mathbf{E}(\mathbf{r}) = -\nabla V(\mathbf{r}) = -\hat{i} \frac{\partial V(\mathbf{r})}{\partial x} - \hat{j} \frac{\partial V(\mathbf{r})}{\partial y}$$

$$= \hat{i} \frac{k_e Q x}{(x^2 + y^2)^{3/2}} + \hat{j} \frac{k_e Q y}{(x^2 + y^2)^{3/2}}$$


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Electric potential for constant electric field:

$\mathbf{E} = \frac{\sigma}{\epsilon_0} \hat{\mathbf{i}}$

$$V = - \int_{x_{ref}}^x \mathbf{E} \cdot d\mathbf{s}$$

$$= - \int_0^x \frac{\sigma}{\epsilon_0} dx'$$

$$= - \frac{\sigma}{\epsilon_0} x \quad \text{for } 0 \leq x \leq d$$

x=0 x=d

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Electric potential for constant electric field:

$\mathbf{E} = \frac{\sigma}{\epsilon_0} \hat{\mathbf{i}}$

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$V_i = 0$ $V_f = - \frac{\sigma d}{\epsilon_0}$

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Electric potential for constant electric field:

$\mathbf{E} = \frac{\sigma}{\epsilon_0} \hat{\mathbf{i}}$

Suppose a proton having charge $e=1.6 \times 10^{-19}$ C is initially at rest at $x=0$, what is its final kinetic energy at $x=d$?

A. 0
 B. $-e\sigma d/\epsilon_0$
 C. $+e\sigma d/\epsilon_0$
 D. $2e\sigma d/\epsilon_0$

x=0 x=d

$V_i = 0$ $V_f = - \frac{\sigma d}{\epsilon_0}$

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Electric potential for constant electric field:

Suppose a proton is initially at rest at $x=0$, what is its final kinetic energy at $x=d$?

$$K_i + U_i = K_f + U_f$$

$$K_f = K_i + U_i - U_f$$

$$K_f = -U_f = eV_f = \frac{e\sigma d}{\epsilon_0}$$

$x=0$ $V_i = 0$ $x=d$ $V_f = -\frac{\sigma d}{\epsilon_0}$

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Uses for accelerated charges:

- In an X-ray machine, electrons are accelerated before hitting a Cu or Mo target that produce X-ray radiation.
 - Note: An electron accelerated through a potential difference of 10V will have $K_f = 10\text{eV} = 1.6 \times 10^{-18} \text{ J}$ $v_f = 2 \times 10^6 \text{ m/s}$
- Electron beam microscopy (almost atomic resolution)
- Accelerated electrons moving in a circle generate synchrotron radiation

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Electric potential for constant electric field:

Suppose a molecule with positive and negative parts is placed in the field E as show.

A. It will move to the right
 B. It will move to the left
 C. It will not move
 D. It will rotate

$x=0$ $V_i = 0$ $x=d$ $V_f = -\frac{\sigma d}{\epsilon_0}$

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